NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO

SUBCONTRACT ACO-9-29067-01
PROCESS DESIGN AND COST ESTIMATE OF CRITICAL EQUIPMENT IN THE BIOMASS TO ETHANOL PROCESS

REPORT 99-10600/15
SECOND-STAGE COUNTERCURRENT REACTOR

FINAL REPORT
OCTOBER 19, 2000

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TABLE OF CONTENTS

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1. SUMMARY

This study developed a cost estimate for the second-stage countercurrent dilute acid process. The results of this study produced two independent process lines, each operating at 1000 bone dry metric tons per day (bdmtpd) for a total of 2000 bdmtpd. The second-stage reactor is a countercurrent vertical type unit (27 ft tall by 66 in. in diameter) designed for 370 psig at 225°C with dilute (0.07%) sulfuric acid injection at the top and the hydrolyzate solids introduced from the bottom. The hydrolyzate is lifted up vertically through the acid by four vertical lift screws and is subjected to the chemical reaction in the digester. The solid products of the reaction are discharged at the top of the digester. The liquid portion of the reaction is drained through the perforated false bottom and drain arrangement. The acid is injected through the top cover to provide a countercurrent material flow. A more detailed description of the process equipment including equipment costs and installation factors is included in the body of this report.

2. INTRODUCTION

Harris Group Inc. (HGI) teamed with Valmet (Sunds Defibrator has recently merged with Valmet) to provide design requirements and develop a cost estimate for equipment in the two-stage countercurrent dilute acid process. While the main focus of this study was the second-stage countercurrent reactor and associated feeders, costs were also developed for a chip washing system and the first-stage reactor. The first stage reactor is a co-current horizontal type unit designed for 150 psig operation at 185°C with steam injection nozzles. The second-stage reactor is a countercurrent vertical type unit designed for 370 psig at 225°C with dilute (0.07%) sulfuric acid injection at the top and hydrolyzate solids introduced from the bottom.

In the chip washing system and first-stage hydrolysis process, all equipment parts in contact with the process are manufactured in AISI 316L stainless steel. Two options were provided for the materials of construction in the second-stage reactor, based on the operating conditions. In the first case, 316L stainless steel was used for all equipment parts in contact with the process. In the second case, the equipment parts in contact with the process are manufactured in Hastalloy C2000.

The technology used for this equipment has been developed and used in the wood pulping industry for many years. The chip washing system utilizes proven technology that has been employed in thermomechanical pulping systems for over 25 years for both hardwood and softwood chips. The reactor technology derives from Valmet's experience with continuous vertical semichemical digester technology and bagasse horizontal digester technology. These systems have capacities up to 1000 tons per day (tpd) and operate at a pressure of 180 psig. The retention time in these digesters is typically 20 to 35 minutes. The vertical digesters generally have a feedstock of hardwood or softwood chips, while the horizontal digester use bagasse, annual fibers, or sawdust. Sunds also designed similar equipment for hydrolysis pilot plants supplied to TVA and NREL.

Plug screw feeders are used to feed the wood chips (or hydrolyzate) into the pressure vessels. This type of device is used extensively in the pulp and paper industry to feed wood chips into digesters or mechanical pulping systems. These feeders have a capacity of 1200 tpd with a 180 psig pressure increase between the inlet and the outlet.

3. DESCRIPTION OF EQUIPMENT

The following describes the equipment required for chip washing, first-stage co-current digester, and the second-stage countercurrent digester. This consists of two 1000 bdmtpd independent lines. A single line diagram of the process as well as additional information on each piece of equipment is included in the appendix.

3.1 Chip Washing

3.1.1 Atmospheric Presteaming (APS) Bin No. 1, Andritz Kone Wood, Model 113 m^3
This unit presteams the screened chips prior to chip washing.

3.1.2 Chute, Model 36”L
This unit connects the presteaming bin to the scrap separator.

3.1.3 Scrap Separator, Model 12’ Wide
This unit agitates and submerges the incoming chips to remove the coarse and heavy contaminants from the chips.

3.1.4 Sump Feed Chute, Model 76”L C-FL
This unit connects the scrap separator to the chip sump.

3.1.5 Circular Chip Sump, Model 243 ft^3
This unit collects the washed chips and circulating water from the scrap separator to provide a head for the chip pump.

3.1.6 Chip Pump
This unit pumps the washed chips and recirculating water to the twin screw drainer.

3.1.7 Chip Cyclone, Model 42”ϕ
This unit further separates sand and contaminates from the chips/wash water slurry.

3.1.8 Large-Capacity Twin Screw Drainer
This unit separates and drains the washed chips from circulating water and discharges the chips into the APS Bin No. 2.

3.1.9 Side Hill Screen, GLV/Celleco Model S-3 6’ wide
This unit removes fines and bark from the recirculating wash water discharged from the twin screw drainer.

3.1.10 Wash Water Cleaner System, Kvaerner Pulping Model DR-9/16
This unit removes sands and contaminants from the recirculating wash water.

3.1.11 Collection Conveyor, Model 26”ϕ
This unit transfers the bark, fines, and contaminants from the dump chambers of the scrap separator and chip cyclone to the scrap thickener.

3.1.12 Inclined Scrap Thickener, Model 258”L Trough
This unit drains the water from the contaminants from the collection conveyor prior to discharging into a dumpster.

3.2 First-Stage Hydrolysis

3.2.1 Chute, Model 40”L
This unit connects the twin screw drainer to APS Bin No. 2.

3.2.2 APS Bin No. 2, Andritz Kone Wood, Model 113 m^3
This unit presteams the washed chips prior to the first stage of hydrolysis.

3.2.3 Chute, Model 48” long.
This unit connects the presteaming bin to the plug screw feeder.

3.2.4 Atmospheric Plug Screw Feeder, Model ADI-500.
This unit compresses the presteamed chips to form a tight plug prior to entering the first stage.

3.2.5 Pressurized Tee-Pipe Assembly, Model 36”ϕ
This unit provides the pressure seal for the first-stage horizontal digester system.

3.2.6 First-Stage Pressurized Horizontal Digester, Model 66”ϕ
This unit produces hydrolyzate. It is 66 in. in diameter and 27 ft long with a paddle-type screw and eight steam nozzles per digester tube. Two horizontal digesters are connected in series per 1000 bdmtpd production line.

3.2.7 Pressurized Chute, Model 60” long.
This unit connects the second horizontal digester to the second-stage pressurized plug screw feeder.

3.3 Second-Stage Hydrolysis

3.3.1 Pressurized Plug Screw Feeder, Model ADI-500
This feeder compresses the partially hydrated feedstock to form a tight plug against the reactor pressure. Regulating the speed of the screw controls the amount of feed exiting the screw feeder.

3.3.2 Pressurized Tee-Pipe Assembly, Model 36”ϕ
This unit provides the pressure seal for the second-stage countercurrent reactor.

3.3.3 Pressurized Shedder Conveyor, Model 20”ϕ
This unit breaks up the hydrolyzate (partially cooked chips) plug formed by the pressurized plug screw feeder and continuously feeds the second-stage vertical digester.

3.3.4 Second-Stage Pressurized Vertical Digester, Model 4 x 28”ϕ

This unit impregnates the hydrolyzate from the shredder conveyor with acid. The impregnated hydrolyzate is lifted up vertically through the acid by four vertical lift screws and is subjected to the chemical reaction in the digester. The solid products of the reaction are discharged at the top of the digester with a horizontal discharge screw conveyor that feeds the third plug screw feeder. The liquid portion of the reaction is drained through the perforated false bottom and drain arrangement. The acid is injected through the top cover to provide a countercurrent material flow.

3.3.5 Pressurized Plug Screw Feeder, Model ADI-500

This unit compresses the solid products from the second-stage vertical digester system to form a tight plug prior to discharging to the tee-pipe assembly.

3.3.6 Pressurized Tee-Pipe Assembly, Model 36”ϕ

This unit provides the pressure seal for the second-stage vertical digester system.

3.3.7 Pressurized Vertical Discharger, Model 36”ϕ

This unit receives the solid product from the countercurrent digester and discharges to a receiving vessel.

4. DISCUSSION

4.1 Throughput Capacity of Currently Produced Equipment

The continuous vertical semichemical digesters and horizontal digester, as well as the chip washer systems, are operating in the pulping industry with capacities up to 1000 tpd. These digesters typically operate at a pressure of 180 psig. The plug screw feeders currently in use operate at a maximum of 1800 tpd; however, the models included in this system have a maximum capacity of 1200 tpd.

4.2 Power Consumption

The anticipated power requirements of the system are summarized below:

System	Connected HP	Demand HP
Chip washing	864	691
First-stage hydrolysis	2360	1888
Second-stage hydrolysis	4600	3680

It should be noted that each of the plug screw feeders require a 1000-hp motor.

4.3 Materials of Construction

In the chip washing system and first-stage hydrolysis process, all equipment parts in contact with the process are fabricated out of 316L stainless steel. For the screw press feeders, the screws and throats will be of cast 316 stainless steel with wear surfaces coated with Stellite 6 material.

Two options were provided for the materials of construction in the second-stage reactor, based on operating conditions. In the first case, where acid is not present, 316L stainless steel was used for all equipment parts in contact with the process. In the second case, where dilute (0.07%) sulfuric acid was present, the equipment parts in contact with the process are manufactured in Hastalloy C2000. In the second case, the screw and throats of the screw press feeders will be Hastalloy C2000 with "Ultimate" overlay on the wear surfaces. It is anticipated that the screws and throats will have to be rebuilt after one or two years of service on washed chip feed.

4.4 Pricing

The equipment price and installation factor for each system are shown below:

System	Equipment Cost	Installation Factor
Chip washing	$ 3,000,000	1.9
First-stage hydrolysis	$ 3,200,000	2.1
Second-stage hydrolysis (316L stainless steel)	$ 7,310,000	2.1
Second-stage hydrolysis (Hastalloy C2000)	$13,510,000	1.5

5. CONCLUSIONS

The basis for this equipment design appears to be sound. The technology has been developed and used in the wood pulping industry for many years. The chip washing system utilizes proven technology that has been employed in thermomechanical pulping systems for over 25 years for both hardwood and softwood chips. The digester technology derives from Valmet's experience with continuous vertical semichemical digester technology and bagasse horizontal digester technology. These systems have capacities up to 1000 tpd and operate at a pressure of 180 psig. The design is based on two separate lines of 1000 tpd in order to meet the production requirement of 2000 tpd. The material selection of 316L stainless steel is appropriate for processes where acid is not present and this is a standard practice in the pulping industry. The selection of Hastalloy C2000 for equipment parts in contact with dilute (0.07) sulfuric acid is acceptable; however, it may be a more expensive material than what is actually required. Corrosion tests performed for NREL indicate that 316L stainless steel has acceptable corrosion rates when exposed to a synthetic hydrolyzate solution with 0.07% sulfuric acid at 225°C; however, Valmet does not feel comfortable supplying 316L stainless steel for a high-temperature acid-based process and would not guarantee 316L stainless steel for that application. There are other cheaper alloys, such as 825, that have acceptable corrosion rates for the process conditions; however, Valmet did not have the time or experience working with these metals to prepare a quote.

6. RECOMMENDATIONS

The operation of this equipment has been proven and the results are relatively predictable for wood chips (either hardwood or softwood); however, information is lacking on the performance of this equipment with other feedstock, such as corn stover. Additional studies are required if the feedstock is changed to corn stover, especially in the area of plug screw feeders operating at high pressures.

Additional studies are also required on the anticipated corrosion rates of a hydrolyzate solution with 0.07% sulfuric acid at 225°C. Without extensive laboratory or pilot data on actual corrosion rates of the process hydrolyzate, vendors and engineers are going to be reluctant to specify, supply, or guarantee equipment that is not fabricated out of higher cost metals.